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Uptake of Cadmium from Phosphate Fertilizers by Peas, Radishes, and Lettuce

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Uptake of Cadmium from Phosphate Fertilizers by Peas, Radishes, and Lettuce

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Uptake of Cadmium from Phosphate Fertilizers by Peas, Radishes, and Lettuce[1]

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ABSTRACT

Cadmium uptake from phosphate fertilizers by radish (*Raphanus sativus* L.), lettuce (*Latuca sativa* L.), and garden peas (*Pisum sativum* L.) was investigated in the greenhouse. Fertilizer in all treatments was applied at the rate of 100 μg P/g soil to pots containing 4 kg soil. When reagent grade mono-calcium phosphate was used as a P source on a coarse-textured acid soil, Cd contents of edible radish roots and tops were < 0.4 μg/g dry weight; while the Cd content of lettuce, and pea seeds and foliage was < 0.2 μg/g. The use of concentrated superphosphate (CSP) containing 174 μg Cd/g resulted in plant Cd levels of 2.4, 3.4, 6.3, 0.9, and 0.5 μg/g for radish roots, radish tops, lettuce, pea seeds and pea foliage, respectively. On a medium-textured calcareous soil the use of this CSP increased the Cd content of radish tops from 0.8 to 1.4 μg/g, while in lettuce the increase was from 0.8 to 1.2 μg/g. The effect on radish roots from calcareous soil was nonsignificant. Pea seeds and foliage on this soil were below our Cd detection limit of 0.2 μg/g. Uptake on both soils was a linear function of the Cd content of the fertilizer.

With the acid soil, uptake of Cd from CSP was essentially the same when the fertilizer was placed in a spot 5 cm below the seed as when mixed with the soil. Di-ammonium phosphate (DAP) containing 157 μg Cd/g resulted in similar uptake to the CSP when mixed with the soil, but spot placement of DAP almost completely eliminated Cd uptake from the fertilizer. In the calcareous soil spot placement increased Cd uptake from the CSP fertilizer but slightly depressed uptake from DAP.

Additional Index Words: **heavy metals, plant uptake, superphosphate, di-ammonium phosphate.**

The cadmium content of phosphate ores used in fertilizer manufacture is highly variable, but ores from the western United States are commonly relatively high in this element. Values of 130 μg Cd/g for Western ore as compared to 9 μg/g for Florida ore have recently been published (USEPA, 1974). In 11 samples of di-ammonium phosphate, (18-20-0, elemental basis), mostly of Western origin, the Cd content ranged from 7.4 to 156 μg/g. Ten samples contained < 50 μg/g while six were in excess of 125 μg/g. Seven samples of concentrated superphosphate (0-20-0, elemental basis) contained from 86 to 114 μg Cd/g (Unpublished data. U.S. Environ. Prot. Agency, Region X, Seattle, Wash.).

Literature is available concerning Cd uptake by plants, but most reports deal with Cd stresses at much higher levels than would occur due to the Cd content of phosphate fertilizers. Schroeder and Balassa (1963) suggest that detectable amounts of Cd may be taken up from this source, and that the resulting Cd levels in the plants might contribute significantly to the body burden of consuming organisms. Significant uptake of Cd from the use of phosphate fertilizers has also been reported in Australia (Williams and David, 1973).

This report described an experiment conducted to evaluate uptake of Cd by some common food crop plants from phosphate fertilizers containing levels of Cd commonly encountered in materials manufactured from Western phosphate ores. Specific objectives of the research included: i) to determine the levels of Cd that might occur in these plants as a result of the use of high Cd fertilizers, and ii) to provide information concerning the effect of soil properties, and the chemical form and placement of phosphate fertilizers, on Cd uptake from these materials.

It was not feasible within the scope of this project to test the Cd uptake from a large number of soils. Therefore, two soils were selected to provide a maximum range of Cd uptake: i) A coarse-textured acid soil in which the activity of Cd^{2+} would remain relatively high, favoring plant uptake, and ii) a calcareous medium-textured soil in which the higher cation exchange capacity and pH would tend to depress Cd^{2+} solubility and uptake (Lagerwerff, 1971; Haghiri, 1974).

MATERIALS AND METHODS

Soils selected for the experiment were Westport fine sand (Typic udipsamment), an acid dune soil from near Bandon, Oreg., and Virtue silt loam (Xerollic durargid), a calcareous soil from near Nyssa, Oreg. Soils were dried, mixed, and crushed to pass a 0.5-cm screen prior to potting. Plants were grown in paraffin-coated paper containers approximately 20 cm in diameter and each containing 4 kg air-dry soil. Selected soil properties are shown in Table 1. In order to improve the water-holding capacity of the Westport soil, 2.5% by weight of an acid peat was mixed with this soil. Analyses of the Westport soil shown in Table 1 were from a sample taken after the peat was added. The measured pH of this soil varied from 4.5 to 5.3 when sampled at different times, apparently due to the low buffering capacity.

Fertilizer materials included concentrated superphosphate (CSP) and di-ammonium phosphate (DAP), with a high and a low Cd level

Table 1—Characteristics of soils used in the Cd uptake experiment

		Westport fine sand	Virtue silt loam
pH 1:2 soil/water		4.5	8.4
Organic matter	% O.M.	0.6	1.19
Total N Kjeldahl	% N	0.01	0.08
CEC Neutral *N* NH_4OAc	meq/100 g	2.2	20.0
Extractable P†	μg/g	11	13
Free carbonates	% as $CaCO_3$	0.0	2.2
Total Cd	μg/g	< 0.5	0.6
Soluble Cd Neutral *N* NH_4OAc	μg/g	0.05	0.1

† $NaHCO_3$ extraction for Virtue soil, dilute HCl-NH_4F for Westport soil.

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Table 2—Treatment materials, amounts, and method of application for Cd uptake experiment

Treatment	Materials†							
		CSP		DAP				
	MCP	Low	High	Low	High	AN	CD-P	Method
	g/pot						μg/pot	
1	1 64	–	–	–	–	1.03	–	Mix
2	–	2.0	–	–	–	1.03	–	Mix
3	–	1.6	0.4	–	–	1.03	–	Mix
4	–	1.2	0.8	–	–	1.03	–	Mix
5	–	0.8	1.2	–	–	1.02	–	Mix
6	–	0.4	1.6	–	–	1.03	–	Mix
7	–	–	2.0	–	–	1.03	–	Mix
8	–	–	2.0	–	–	1.03	–	Spot
9	–	–	–	–	2.0	–	–	Mix
10	–	–	–	–	2.0	–	–	Spot
11	–	2.0	–	–	–	1.03	840	Mix
12	–	2.0	–	–	–	1.03	840	Spot
13	–	–	–	2.0	–	–	790	Mix
14	–	–	–	2.0	–	–	790	Spot

† MCP—Monocalcium ortho-phosphate, reagent.
CSP (low)—concentrated superphosphate, 0–20–0, 12 ppm Cd.
CSP (high)—concentrated superphosphate, 0–20–0, 174 ppm Cd.
DAP (low)—Di-ammonium phosphate, 18–20–0, 7 ppm Cd.
DAP (high)—Di-ammonium phosphate, 18–20–0, 157 ppm Cd.
AN—Ammonium nitrate, reagent.
Cd-P—Cadmium phosphate, $Cd(H_2PO_4)_2 \cdot 2H_2O$, 39% Cd by analysis.

sample of each. The high Cd CSP contained 174 μg Cd/g, while the low Cd CSP contained 12 μg/g. The high and low Cd level samples of DAP contained 157 and 7 μg/g, respectively. The high and low Cd level samples of these fertilizers were from entirely different sources, so the chemical compositions may not have been identical, although both CSP samples were nominally 0–20–0 and both DAP samples 18–20–0 (elemental basis). In addition to the above materials, reagent grade mono-calcium phosphate (MCP), and cadmium dihydrogen phosphate prepared in the laboratory ($Cd[H_2PO_4]_2 \cdot 2H_2O$) were used in selected treatments (Table 2). The material as prepared was analyzed by atomic absorption spectrophotometry and found to contain 39% Cd as compared to a predicted value of 33%. All treatments supply a total of 100 μg P/g of soil. Ammonium nitrate was added to the CSP and MCP treatments to supply the same total N as the DAP. In addition to the materials shown in Table 2, KNO_3 and K_2SO_4 were added to the soil in amounts sufficient to supply 75 μg K, 15 μg S, and 13 μg additional N per g soil.

The set of 14 treatments contains two subsets. In the first subset all treatments were thoroughly mixed with soil using a twin shell blender. Treatment 1 used reagent grade MCP containing no Cd. Treatment 2 used the low Cd CSP, while in treatments 3–7 increasing amounts of high Cd CSP were substituted for the low Cd CSP. This results in treatments 1 through 7 supplying 0.0, 0.007, 0.023, 0.039, 0.055, 0.071, and 0.087 μg Cd per g soil, respectively.

Treatments 7–14 comprise a second subset, a 2^3 factorial with two types of materials (CSP and DAP), two placements (mix and spot), and two sources of Cd (native and added as Cd-P). This set was designed to evaluate the effect of fertilizer material, placement, and Cd source on the uptake of Cd by the test crops. The spot placement was intended to simulate band application in the field. Materials were placed in a single spot located at the center of the pot and 5 cm below the soil surface. Lateral distance from the seed to the spot was also approximately 5 cm. The Cd source comparison is intended to evaluate the effect of adding $Cd(H_2PO_4)_2 \cdot 2H_2O$ as compared to a similar amount of native Cd in fertilizer. In the factorial subset all DAP treatments add a total of 0.080 μg Cd/g soil, while all CSP treatments add 0.087 μg/g.

Three common garden crops were grown; garden peas (*Pisum sativum* L. cultivar Little Marvel), radish (*Raphanus sativus* L., cult. early Scarlet Globe), and leaf lettuce (*Lactuca sativa* L., var. *crispa* cult. Oak Leaf). Two replications were placed in a completely random arrangement. Total pots in the experiment numbered 168. Pots were planted 27 Mar., with the exception of the garden peas on the Westport soil which were planted 4 Apr. Plants were thinned to six per pot for radishes and lettuce and three plants per pot for peas shortly after emergence. Temperatures in the greenhouse were 23.9 ± 2.8°C day, and 18.3 ± 5°C night. Supplemental light was provided for 14 hours during the day by a combination of cool and warm white fluorescent tubes.

Field capacity moisture percentages (wt/wt) were determined for each soil by applying water to the surface of a soil column and gravimetrically determining the soil water content above the wetting front after allowing a 24-hour equalization period. Pots were weighed daily and deionized distilled water added to replace loss by evapotranspiration. Initially the total weight maintained corresponded to about 75% of field capacity. This total weight was increased to field capacity as roots were established and evaporative demand increased.

Radishes were harvested 1 May. The edible root portions and the tops were harvested separately. Lettuce was harvested 8 May. The tap root constituted only a very small portion of the total weight, and this was not included in the foliar sample. Plants were rinsed with deionized water, fresh weight determined after blotting, and dry weight determined after freeze drying. Peas from the Virtue soil were harvested 28 May and from the Westport soil on 2 June. Seeds were separated from the remaining above-ground portions. No roots were harvested. Pea materials were not rinsed except for a few basal portions of stems that were contaminated with soil.

For Cd analysis a 1-g freeze-dried ground sample was digested in a block digestor with 2:1 nitric-perchloric acid. Samples were brought up to 10 ml and analyzed for Cd by flame atomic absorption spectrophotometry.

With the dilutions as utilized, levels above 0.2 μg Cd/g could be consistently distinguished from background, and this amount is considered to be our lower detection limit. Eleven replicates of National Bureau of Standards (NBS) orchard leaves containing 0.11 μg Cd/g were analyzed and all were found to be below the 0.2 μg/g detection limit. Cadmium "spikes" were added to 27 of the samples in amounts calculated to give final concentrations between 4.7 and 10.9 μg Cd/g. Analysis of these "spiked" samples gave values averaging 101% of theoretical, and ranging between 83 and 128% with a standard deviation of 14%. This precision of recovery was rather low but the differences were essentially random with no evidence of bias. Precision of duplicate samples of the experimental material were satisfactory. Only 3 of 29 duplicates run at different times varied by >0.10 μg/g.

For total P analysis 50 mg of dried, ground plant samples were digested in a block digestor using H_2SO_4, K_2SO_4, and HgO (Kjeldahl digestion). The P was then determined colorimetrically on an automated analyzer using molybdophosphoric acid reduced to a molybdenum blue complex with ascorbic acid.

Standard least squares analysis of variance and regression techniques were utilized. However, in some of the data sets involving Cd content of plants, tests of homogeneity revealed that logarithmic transformations were appropriate prior to the use of the analysis of variance. Significance of main effects are generally not shown on the accompanying tables where major interactions are present.

RESULTS AND DISCUSSION

The progressive replacement of the low Cd CSP with the high Cd CSP did not affect dry-matter yields for any of the crops on either soil. Radish and lettuce plants in treatments 1–7 appeared healthy and grew well on both soils. Pea plants in some pots exhibited early senescence and poor growth, but this did not appear to be related to treatment as duplicate pots were not consistent. Phosphorus levels in the plants were high (Table 3), indicating that the fertilizer was being adequately utilized with the possible exception of the pea foliage on the Virtue soil. The radish tops from the Westport soil contained 1.10% P, which might be excessive but growth was not adversely affected. The absence of any growth effects due to treatments in this subset simplifies interpretation of the plant Cd concentration data, as dilution or

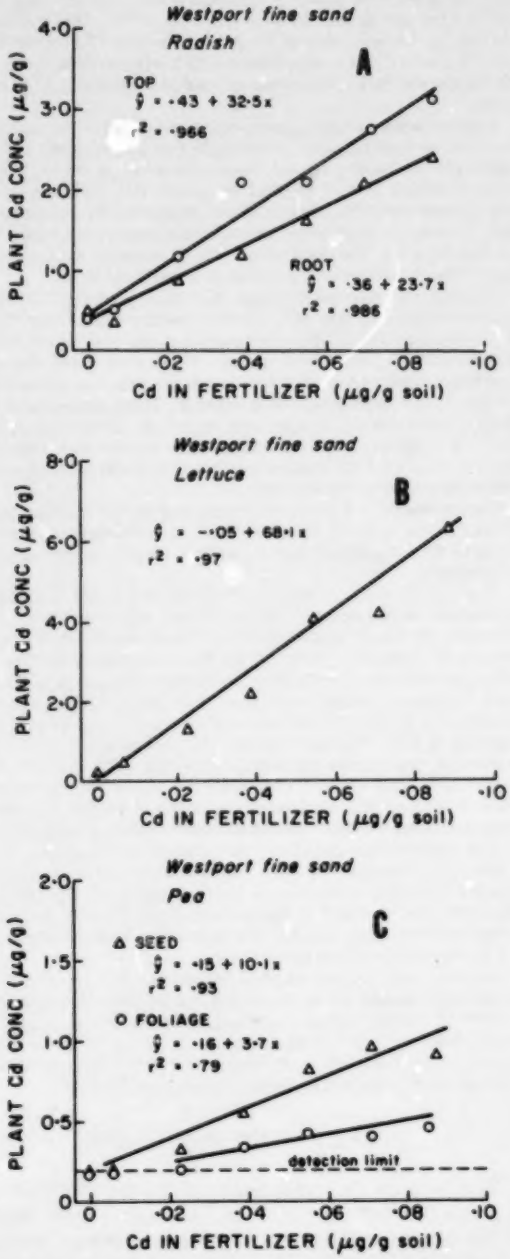

Fig. 1—Cd content of plants grown on a coarse-textured acid soil as a function of the Cd contained in concentrated superphosphate fertilizer: (A) radish; (B) lettuce) (C) pea.

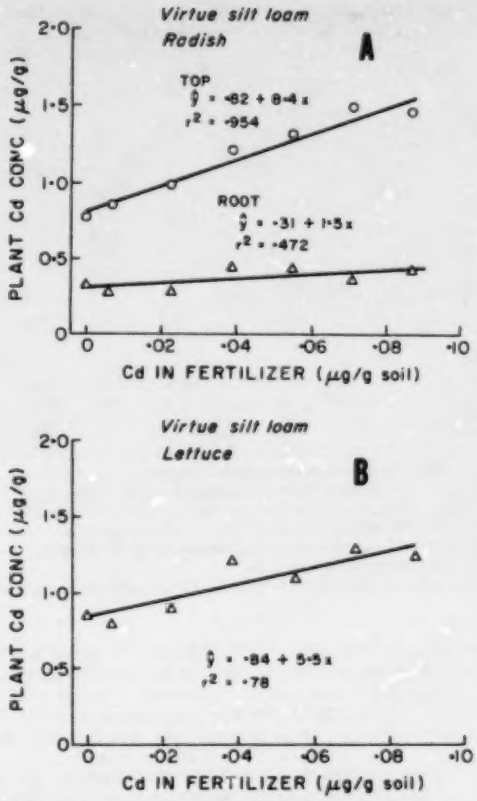

Fig. 2—Cd content of plants grown on a medium-textured calcareous soil as a function of the Cd contained in concentrated superphosphate fertilizer: (A) radish; (B) lettuce.

concentration effects due to growth differences are not likely to be important.

The Cd concentrations in plants grown on the Westport fine sand increased markedly when the high Cd CSP was substituted for the low Cd CSP (Fig. 1). Radish roots and tops from this soil contained about 0.4 μg Cd/g of dry weight when the fertilizer contained no Cd, increasing to 2.4 μg/g in the root and 3.4 μg/g in the tops when all of the fertilizer was the high Cd CSP. The increase in Cd in the lettuce was from <0.2 to 6.3 μg/g. Cd increased from below the detection limit of 0.2 μg/g to about 0.9 μg/g in the pea seeds and 0.5 μg/g in the pea foliage. These results were highly significant and appear to be linearly related to the Cd contained in the fertilizer. Some difficulty was encountered with the regression analysis of the pea data on this soil, as the low levels of Cd fertilizer resulted in plant levels below our analytical detection limit. In these cases the highest Cd treatment registering at or below 0.2 μg Cd/g was assumed to be 0.2, and values from the lower treatment levels were not used in the calculation. This procedure resulted in the inclusion of six treatments in the regression for pea seeds and five treatments for pea foliage.

The effect of increasing Cd in the fertilizer on Cd levels in the plants was less dramatic on the Virtue soil, but it was detectable in the radishes and lettuce. Cadmium in the pea foliage and seeds from this soil were almost all below our detection limit of 0.2 μg/g and are not reported here. Cadmium concentration in radish tops increased from 0.8 to 1.4 μg/g by using high Cd CSP, and the increase in lettuce was from 0.8 to 1.2 μg/g. Here again the increase was highly significant and apparently a linear function of Cd in the fertilizer (Fig. 2). The rates of increase were much lower than those on

Table 3—Dry matter percentage, dry weight yields, and plant P concentrations for treatments 1–7 of Cd uptake experiment. Values represent means of 14 pots

	Westport fine sand			Virtue silt loam		
	Dry matter	Dry weight	Plant P	Dry matter	Dry weight	Plant P
	%	g/pot	%	%	g/pot	%
Radish						
Root	5.27	3.67	0.66	5.88	4.49	0.35
Top	5.63	3.84	1.10	7.15	2.11	0.37
Lettuce	5.25	5.52	0.46	4.82	5.99	0.49
Pea						
Seeds	26.6	4.80	0.68	31.5	6.41	0.62
Foliage	21.9	8.77	0.35	48.1	5.81	0.19

the Westport soil. Cadmium in radish roots on the Virtue soil apparently increased slightly but the hypothesis of a zero slope could only be rejected at the 0.1 probability level and not at the 0.05 level.

The effect of soils and crops on Cd uptake from CSP can be evaluated from Table 4. With the exception of radish roots, the intercepts were much lower on the Westport fine sand than on the Virtue silt loam, indicating a higher background level of Cd uptake for the Virtue soil. The Westport soil was from a dune area and undoubtedly had never been fertilized. The Virtue soil was collected outside a cultivated field near a country road and, while it apparently had not been fertilized, the history is less certain.

The most striking effects are in the slopes and the percentages of the Cd contained in the fertilizer that was found in the plants. The slopes represent the increase in Cd in the plant (μg/g dry weight) per unit of Cd in the fertilizer applied (μg/g soil). Slopes for the lettuce and radishes on the Westport fine sand were in the range of 24 to 68 as compared to 1.5 and 8.4 on the Virtue soil (Table 4). This comparison cannot be made for the peas due to the lack of detectable amounts in the plants grown on the Virtue soil. The percentage of the Cd applied in the fertilizer that is recovered in the plants is calculated from the slope, mean dry matter produced, and the amount of soil in the pot. For radish tops plus edible roots this recovery was 5.29% on the Westport fine sand as compared to 0.61% on the Virtue silt loam. For lettuce the recovery was 9.40% on the Westport and 0.82% on the Virtue soil. The higher recovery of Cd by lettuce than radish is in agreement with the results of Haghiri (1973), even though he applied much higher levels of Cd than are found in fertilizers. Cadmium recovery from fertilizer was lower in peas than in radish and lettuce. The 5.29 and 2.02% of applied Cd found in radish and pea plants, respectively, when grown on Westport fine sand, are comparable to the results of Williams and David (1973), who found 6.3 and 3.3% of the Cd applied in a single superphosphate taken up by these crops from a podzolic soil with a cation exchange capacity of 5.3 meq/100 g. The difference in recovery of fertilizer Cd uptake from the two soils used in this experiment is exactly what would have been expected, as the high pH associated with the free $CaCO_3$, as well as the higher cation exchange capacity of the Virtue soil would tend to depress uptake (Lagerwerff, 1971; Williams and David, 1973; Haghiri, 1974). These two soils should represent near maximum and minimum recovery.

The percentage of the native soil Cd, as measured by either the total Cd or ammonium acetate-extractable Cd, that is recovered by the plants can be similarly calculated using the intercepts and the Cd in the soil (Table 1). Comparison of these recovery percentages with the recovery of Cd applied in the fertilizer allows us to compare the relative susceptibility of native and applied Cd to plant uptake. The percentage of the total Cd taken up could only be calculated for the radishes and lettuce on the Virtue soil, where 0.13 and 0.21% were taken up, respectively, compared to 0.61 and 0.82% from the Cd in the fertilizer. On this soil at least it appears that the fertilizer Cd is four or five times more available to the plant than the total native soil Cd. The fraction of the ammonium acetate-extractable Cd recovered in the plants was lower than for fertilizer Cd in the acid Westport soil, but somewhat higher than that for fertilizer Cd on the Virtue silt loam (Table 4).

Fertilizer material and placement had a marked effect on Cd uptake, particularly on the acid Westport soil. Cadmium source effects, i.e., fertilizer containing high

Table 4—Summary of the percentages of soil and added Cd found in plants and regressions of plant Cd content on the Cd added in fertilizer

	Westport fine sand				Virtue silt loam				
			Uptake†				Uptake†		
Plant	Intercept	Slope‡	Extractable Cd	Fertilizer Cd	Intercept	Slope‡	Total Cd	Extractable Cd	Fertilizer Cd
	μg/g		%		μg/g		%		
Radish									
Root	0.36	23.7	0.66	2.17	0.31	1.5(NS)	0.06	0.36	0.17
Top	0.43	32.5	0.83	3.12	0.82	8.4	0.07	0.43	0.44
			1.49	5.29			0.13	0.79	0.61
Lettuce	−0.05	68.1	–	9.40	0.84	5.5	0.21	1.26	0.82
Pea									
Seed	0.15	10.1	0.36	1.21	–	–	–	–	–
Foliage	0.16	3.7	0.70	0.81					
			1.06	2.02					

† Uptake is % of the total and extractable Cd found in the plants as calculated from the intercept and % of the fertilizer Cd found in plant calculated from the slope.

‡ μg Cd/g plant per μg fertilizer Cd/g soil.

Table 5—The effect of fertilizer placement of plant Cd levels resulting from the uptake of Cd in concentrated superphosphate (CSP) and di-ammonium phosphate (DAP). Means of four pots averaged over native fertilizer and added Cd treatments

	Radish		Lettuce	Pea	
	Roots	Tops	tops	Seeds	Foliage
	μg Cd/g dry weight				
Westport fine sand					
CSP-mix	3.0	3.9	5.8	5.7	0.8
CSP-spot	2.6	5.1	5.2	5.8	0.9
DAP-mix	3.8	2.5	4.8	5.7	0.9
DAP-spot	0.3	<0.2	0.2	<0.2	<0.2
Placement × material interaction	**	**	**	**	**
Virtue silt loam					
CSP-mix	0.4	1.6	1.2	Below detection	
CSP-spot	1.0	2.9	2.9	limit of 0.2	
DAP-mix	0.4	1.5	1.3		
DAP-spot	0.5	1.0	0.9		
Placement × material interaction		**	**		

** Probability of type I error ≤0.01.

native Cd vs. low Cd fertilizer to which $Cd(H_2PO_4) \cdot 2H_2O$ was added, were relatively minor, so the data shown in Tables 5–7 are averaged over Cd source. On the Westport soil the placement of CSP had little or no effect on the Cd level in the plants, and Cd uptake from DAP mixed with the soil was similar to the uptake from CSP. The spot placement of DAP, however, almost completely eliminated uptake of Cd from the fertilizer, regardless of crop or plant part (Table 5). Unfortunately, in this treatment subset there were growth effects caused by differences in fertilizer material that must be considered in the interpretation of the plant Cd levels (Table 6). Spot placement depressed the yields of radish tops and especially of lettuce on the Westport soil, but these effects occurred regardless of whether the material was CSP or DAP and, therefore, cannot explain the absence of Cd uptake due to spot placement of DAP. On this soil there was also a tendency for yields to be lower

Table 7—The effect of placement of concentrated superphosphate (CSP) and di-ammonium phosphate (DAP) on plant P levels. Means of four pots, averaged over fertilizer sources

	Radish		Lettuce	Pea	
	Roots	Tops	tops	Roots	Tops
	% P				
Westport fine sand					
CSP-mix	0.62	0.99	0.53	0.65	0.31
CSP-spot	0.53	1.10	0.49	0.66	0.36
DAP-mix	0.72	1.51	0.64	0.63	0.52
DAP-spot	0.73	1.54	0.56	0.62	0.62
(Material)	**	**	**		**
Virtue silt loam					
CSP-mix	0.35	0.37	0.48	0.64	0.18
CSP-spot	0.30	0.36	0.44	0.51	0.13
DAP-mix	0.39	0.42	0.48	0.66	0.23
DAP-spot	0.19	0.27	0.38	0.51	0.13
(Placement)	**	**	**	**	**
(Material)	*	*	*		*
(Placement × material)	*	*	*		*

*,** Probability of type I error ≤0.05 and ≤0.01, respectively.

Table 6—The effect of placement of concentrated superphosphate (CSP) and di-ammonium phosphate (DAP) on plant dry matter yields. Mean of four pots, averaged over fertilized sources

	Radish		Lettuce	Pea	
	Roots	Tops	tops	Seeds	Foliage
	g dry matter/pot				
Westport fine sand					
CSP-mix	4.03	3.90	4.60	4.16	3.80
CSP-spot	3.11	3.01	0.79	4.78	6.39
DAP-mix	1.91	2.55	4.78	3.66	3.91
DAP-spot	2.57	2.24	1.35	2.31	2.66
(Material)	**	**			
(Placement)		**	**		
Virtue silt loam					
CSP-mix	4.29	2.06	5.16	5.30	6.21
CSP-spot	2.92	1.64	2.03	5.89	4.89
DAP-mix	4.28	2.12	5.69	5.79	5.61
DAP-spot	2.61	1.64	2.12	2.66	5.69
(Placement)	**	**	**		*

*,** Probability of type I error ≤0.05 and ≤0.01, respectively.

when DAP was used than with CSP, even though DAP resulted in slightly higher plant P levels (Table 7). Spot placement of DAP did not lower the P in the plants, so apparently the absence of Cd uptake cannot be attributed to lack of utilization of the fertilizer. The reason for the lack of Cd uptake from spot-placed DAP on this acid soil is not known, but it is most likely related to the neutral or basic reaction of this fertilizer as compared to the more acid CSP. The effect should be further investigated as it may have important implications concerning management techniques.

The effects of fertilizer materials and placement were quite different on the calcareous Virtue soil. Most yields were depressed by spot placement of either fertilizer (Table 6). This was apparently due to decreased P uptake by plants on this soil from spot placement, particularly from spot-placed DAP (Table 7). The pattern of material and placement effects on Cd uptake (Table 5) did not match that for yields. The Cd uptake by radish tops and lettuce on the Virtue soil appeared to be enhanced by spot placement of CSP and depressed by the spot placement of DAP, but this depression was not of the magnitude of the depression due to spot placement of DAP on the acid soil. Apparently, on both soils the factors controlling Cd uptake from the fertilizers are different from those controlling the P uptake, a result that should not be surprising considering the widely different chemical nature of the two elements.

As noted above, the effects of Cd source on uptake were minor compared to the effect of fertilizer materials and placement. However, a small apparent (probability ≤0.05) increase in uptake from the use of Cd-P as compared to native Cd fertilizer was noted in radishes grown on the Westport soil. The use of the Cd-P resulted in an average of 2.8 μg Cd/g in the radish roots and 3.7 μg/g in the tops as compared to 2.0 μg/g in the roots and 2.1 μg/g in the tops from native Cd fertilizer. No difference due to sources could be detected in the other crops nor in any of the crops on the Virtue soil. It appears that cadmium dihydrogen phosphate results in similar or perhaps slightly higher Cd uptake than the Cd found in fertilizers.

LITERATURE CITED

1. Haghiri, F. 1973. Cadmium uptake by plants. J. Environ. Qual. 2:93–95.
2. Haghiri, F. 1974. Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc, and soil temperature. J. Environ. Qual. 3:180–183.
3. Lagerwerff, J. V. 1971. Uptake of cadmium, lead and zinc by radish from soil and air. Soil Sci. 111:129–133.
4. Schroeder, H. A., and J. J. Balassa. 1963. Cadmium: uptake by vegetables from superphosphate in soil. Science 140:810–820.
5. U.S. Environmental Protection Agency. 1974. Development document for effluent limitations guidelines and new source standards for the basic fertilizer chemicals. EPA-440/1-74-011-A, Washington, D.C.
6. Williams, C. H., and D. J. David. 1973. The effect of superphosphate on the cadmium content of soils and plants. Aust. J. Soil Res. 11:43–56.